



UNIVERSITÉ DE GENÈVE

NLR-Memorandum AMSTR-NLR-TN-18-Issue03
TTCS Accumulator Specification

Sun Yat-Sen University (SYSU)
National Aerospace Laboratory (NLR)
Istituto Nazionale di Fisica Nucleare (INFN)

Distribution:

No part of this document may be reproduced and/or disclosed, in any form or by any means, without the prior written permission of NLR.

Division:

Aerospace Systems & Applications

Prepared:

J. van Es/T. Zwartbol

Approved:

P. Dieleman

Order-/codenumber:

2497304

Issued:

December 2007

Classification title:

Unclassified

**Document change log**

issue	date	description
Draft	August 2004	Initial distributed to partners as NLR-Memorandum AMSTR-NL-TN-2004-017 Draft (wrong numbering)
Issue01	16 February 2006	Included Document Change log
		Abbreviations list included
		Shorter introduction
		Change of operating and non-operating temperature requirements ACC-013 and ACC 014 according to AMSTR-NLR-TN-31-Issue01 TTCS Box Temperature Requirements
		Compatibility with electronics H/W is detailed with specs of proposed TEC's and heaters
		Change of accuracy of temperature control ACC19-01 to 1 °C
		Change of orientation requirement ACC25-01
		Update loop lay-outs
		Update of the planning
		added vibration test requirements
		added Minimum Workmanship vibration test levels (in Appendix I)
		added design loads requirement accumulator mounting
		added EMC requirements
		added EMC requirements applicable to AMS02 (Appendix III)
Draft issue 2		Adding details on documentation for qualification of the design
Issue02	November 2006	Update of requirements according to MoM AMS TTCS CDR 30-31 October 2006 CERN
		Update delivery dates p18
		Update deliverable documentation p19
		Delete TTCS Planning (CAST will be informed of regular updates)
		Update mass, volume and envelope reqs p21
		Update ACC-04 and ACC06 p22
		Update leak tightness requirement p23
		Update ACC-16 update shock requirement p24
Issue03	November 2007	Added vibration test fail/pass criteria
		Mass requirement updated
		Update of TTCS schematics
		Update of delivery dates H/W



Contents

Abbreviations	6
1 Scope of the document	7
1.1 Reference documents	7
2 AMS Introduction	7
2.1 Alpha Magnetic Spectrometer (AMS)	7
2.2 Tracker Thermal Control System for AMS-02	8
2.3 TTCS loop lay-out	9
2.4 Principal functionality of the components	11
3 General Accumulator	12
3.1 Accumulator Functions	12
3.1.1 Evaporation temperature set-point control	12
3.1.2 Account for volume changes due to temperature changes	12
3.1.3 Account for volume changes during operation	13
3.2 Accumulator design challenges	13
3.3 Location TTCS Component Boxes	14
4 Product specific Statement of Work	17
4.1 Tasks	17
4.2 TTCS Model Philosophy	17
4.2.1 Accumulator design philosophy	18
4.2.2 Deliverable hardware	18
4.2.3 Deliverable documentation	19
5 Technical requirements	21
5.1 Physical requirements	21
5.1.1 Mass (Req. id. ACC01-01)	21
5.1.2 Volume (Req. id. ACC02-01)	21
5.1.3 Envelop (Req. id. ACC03-01)	21
5.2 Mechanical Interfaces	22
5.2.1 Mounting interfaces (Req. id. ACC04-01)	22
5.2.2 Electrical interfaces (Req. id. ACC05-01)	22
5.2.3 Fluidic interface with the loop (Req. id. ACC06-01)	22
5.3 Design pressures and loads requirements	23



5.3.1	Maximum Design pressure (Req. id. ACC07-01)	23
5.3.2	Proof pressure (Req. id. ACC08-01)	23
5.3.3	Burst pressure (Req. id. ACC09-01)	23
5.4	Accumulator leak tightness (Req. id. ACC10-01)	23
5.5	Fluid compatibility (Req. id. ACC11-01)	23
5.6	Environmental Requirements	24
5.6.1	Thermal Control (Req. id. ACC12-01)	24
5.6.2	Operating temperatures (Req. id. ACC13-01)	24
5.6.3	Non-operating temperatures (Req. id. ACC14-01)	24
5.6.4	Vacuum conditions (Req. id. ACC15-01)	24
5.6.5	Vibration and shock requirements (Req. id. ACC16-01)	24
5.6.6	Electro Magnetic Compatibility (Req. id. ACC17-01)	24
5.6.7	Radiation levels (Req. id. ACC18-01)	25
5.7	Functional and Design Requirements	26
5.7.1	Accumulator Temperature control (Req. id. ACC19-01)	26
5.7.2	Accumulator emergency set-point change (Req. id. ACC20-01)	26
5.7.3	Cleanliness requirements (Req. id. ACC21-01)	26
5.7.4	Lifetime (Req. id. ACC22-01)	26
5.7.5	Maintenance (Req. id. ACC23-01)	26
5.7.6	Sealing (Req. id. ACC24-01)	27
5.7.7	Orientation (Req. id. ACC25-01)	27
5.7.8	Operation in μ -g environment (Req. id. ACC26-01)	27
5.7.9	Rupture criteria (Req. id. ACC27-01)	27
5.8	Compatibility with TTCS (Electronics) design	27
5.8.1	Mechanical Interface with Peltier elements	28
5.8.2	Mechanical Interface with heater elements	28
5.8.3	Thermal Interface with Peltier elements	28
5.8.4	Thermal Interface with heater elements	29
5.9	General requirements	29
5.9.1	Space shuttle launch (Req. id. ACC28-01)	29
5.9.2	ISS (external site) (Req. id. ACC29-01)	29
5.9.3	Prohibited materials (Req. id. ACC30-01)	29
5.9.4	Serial numbers (Req. id. ACC31-01)	29
5.9.5	Non conformance reporting (Req. id. ACC32-01)	29
5.9.6	Quality (Req. id. ACC33-01)	29
5.9.7	Material traceability	29
5.9.8	Acceptance	30



Appendix I: TTCS Structural Verification Requirements Summary	31
A. Structural verification for flight components:	31
B: Structural verification for pressurised systems:	32
C: Fracture analysis:	33
D: Random vibration requirements: Minimum Workmanship Vibration Test Levels	34
Appendix II: Example Compliance Matrix	35
Appendix IV: EMC requirements applicable to AMS-02	39
(41 pages in total)	



Abbreviations

ACOP	Alpha Magnetic Spectrometer Crew Operations Post
ADC	Analogue-to-Digital Converter
AMS	Alpha Magnetic Spectrometer
ANSI	American National Standards Institute.
APS	Absolute Pressure Sensor
CAN	Controller Area Network
Ctrl	Control
DAC	Digital-to-Analogue Converter
DPS	Differential Pressure Sensor
EGSE	Electronic Ground Support Equipment
Htr	Heater
INFN	Istituto Nazionale di Fisica Nucleare, Perugia, Italy
ISS	International Space Station
JMDC	Main DAQ Computer
LFM	Liquid Flow Meter
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory NLR)
PDB	Power Distribution Box
POCC	Payload Operations Control Centre
PWM	Pulse Width Modulation
RD	Reference Document
TRD	Transition Radiation Detector
SYSU	Sun Yat-Sen University Guangzhou China
TEC	Thermo Electric Cooler
TTBP	Tracker Thermal Control system Backplane
TTCB	Tracker Thermal Control system Component Box
TTCE	Tracker Thermal Control system Control Electronics
TTEC	Tracker Thermal Control system Electronic Control board
TTEI	Tracker Thermal Control system Electronics Interface board
TPPC	Tracker Thermal Control system Pump Control board
TPPD	Tracker Thermal Control system Power Distribution
TTPT	Tracker Thermal Control system RTD interface board

1 Scope of the document

The objective of this specification is to describe the requirements for the accumulator for the AMS TTCS CO₂-cooling loop. The requirements are based on the TTCS-system design and on general requirements on space hardware.

1.1 Reference documents

RD-1	TN AMS TTCS BBM/EM Design Description	To be finalised
RD-2	Requirements for the manufacturing and space qualification of all the pressurised weld joints in the AMS TTCS evaporator, revision B, B. Verlaat, 2 Sept. 2003	ASR-S-001
RD-3	NASA- document “Simplified Design Options for STS-Payloads”	JSC-2045RevA

2 AMS Introduction

2.1 Alpha Magnetic Spectrometer (AMS)

The Alpha Magnetic Spectrometer (AMS) is a space born detector for cosmic rays built by an international collaboration. AMS will operate aboard the truss of the International Space Station (ISS) for at least 3 years, collecting several billions of high-energy protons and nuclei. The main goal is to search for cosmic antimatter, (that is for anti-helium nuclei primarily), for dark matter and lost matter.

A first version of the detector, known as AMS-01, flew aboard the Space Shuttle Discovery during the STS-91 mission (2-12 June 1998), collecting about hundred millions of cosmic particles. This trial mission confirmed the main ideas of the project and gave important suggestions for further development.

For the ISS mission, the detector will be slightly different in concept, achieving a higher resolution. In fact, AMS-02 will be an “improved” version of AMS-01. The solid magnet of the AMS-01 mission will be replaced by a more powerful Helium cooled super-conductive cryo-magnet in AMS-02. The introduction of the cryo-magnet does not only introduce additional

magnet cooling, it also increases the thermal design complexity of the Tracker Thermal Control System (TTCS).

In AMS-01, the massif solid magnet was used to collect the heat produced by the Tracker electronics. The strict temperature stability requirements could be easily met due to the good thermal connections from the electronics to the magnet that has a very large heat capacity. In AMS-02, the super-conductive magnet does not provide this large heat capacity and therefore an active thermal design is required to meet the stringent electronics temperature stability requirements.

2.2 Tracker Thermal Control System for AMS-02

The AMS-02 Tracker Thermal Control System (TTCS) is a two-phase cooling system developed by NIKHEF (The Netherlands), Geneva University (Suisse), INFN Perugia (Italy), Sun Yat Sen University Guangzhou (China) and NLR (The Netherlands). The TTCS is a mechanically pumped two-phase carbon dioxide cooling loop. The main objective is to provide accurate temperature control of AMS Tracker front-end electronics. An additional objective is to prove and qualify a two-phase pumped cooling in orbit and collect operational data in micro-g environment over a period of three years.

The two-phase loop incorporates a long evaporator, picking up the heat from the multiple heat-input stations evenly distributed over the six silicon planes. The heat is transported to a condenser connected to a heat pipe radiator. The liquid is transported back to the evaporator by means of a mechanical pump.

The objective of the cooling system is to collect the dissipated heat at the tracker electronics and transport the heat to two dedicated radiators. One radiator is located at the top WAKE (anti-flight direction) side and the other one at the RAM (flight direction) side of the AMS instrument.

The heat producing elements, the tracker front-end hybrid electronics are situated at the periphery of the tracker silicon planes and are located inside the cryogenic magnet. A total of 144 Watt is produced at 192 locations and an additional 6-10 Watt cooling capacity is required for additional electronics.

The thermal design challenges of the TTCS for ASM-02 are:

- Compatibility with the existing Tracker Hardware.
- Limited volume.
- Multiple and widely distributed heat inputs up to 160 W.
- Minimal temperature gradients of less than 1°C

- Low mass budget < 72.9 kg, low power budget < 80 watt.
- High reliability i.e. fully redundant system design.
- Two radiators thermally out of phase.

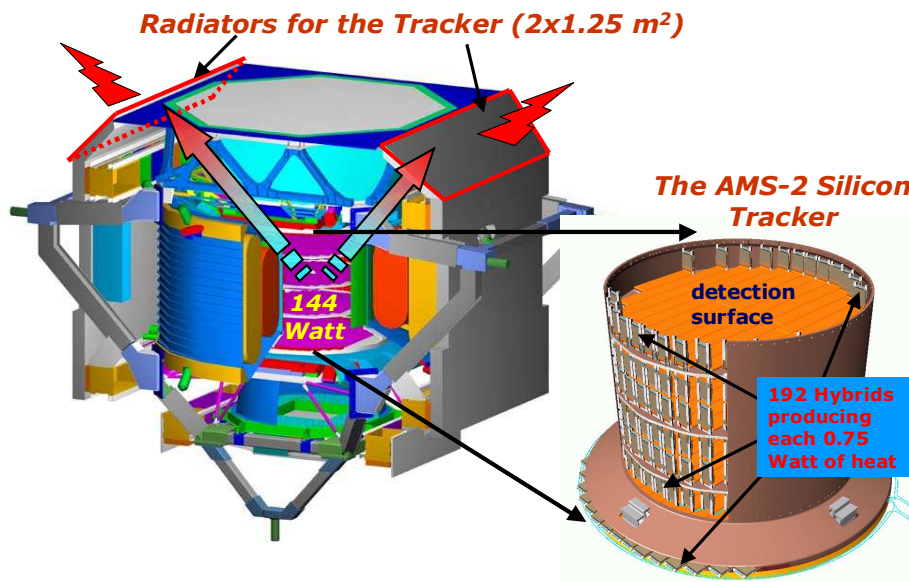


Figure 2-1: AMS-02 Silicon Tracker Schematic

2.3 TTCS loop lay-out

The main functionality of the TTCS loop is to transport heat dissipated by the tracker electronics to radiators that radiate the heat to deep space.

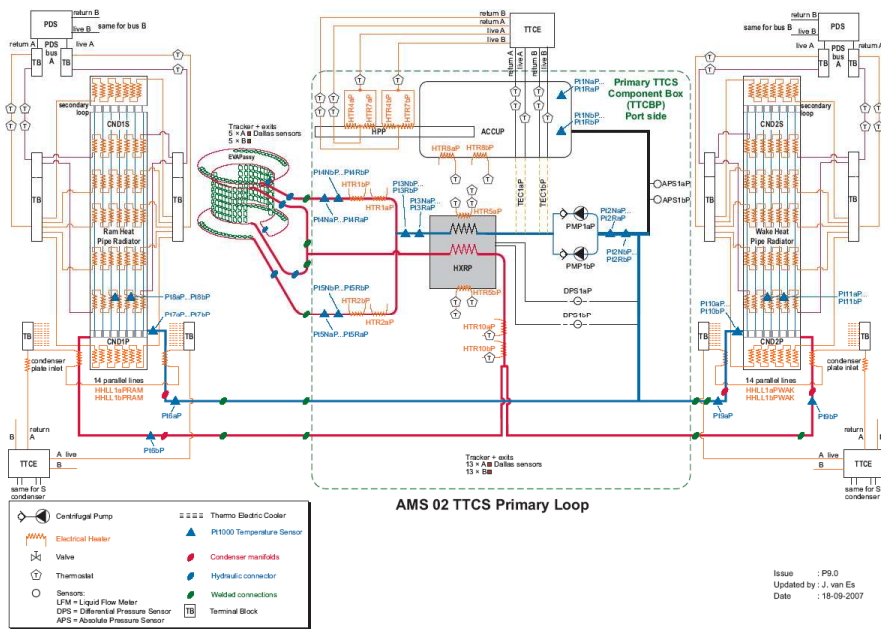


Figure 2-2: Schematic of the Tracker Thermal Control System Primary Loop

After the mixing point of the two radiator branches, the sub-cooled fluid passes the accumulator. By controlling the accumulator temperature the evaporator set-point temperature is

controlled by Peltier elements (cooling) and heaters. The set point can be varied to avoid extreme sub-cooling or operation with liquid temperature just below saturation at the inlet of the pump. A distinct amount of sub-cooling (2,5-5 $^{\circ}\text{C}$) is required to avoid cavitation at the pump. Behind the pump the sub-cooled fluid is warmed up in the heat exchanger before it enters again the pre-heater section. The primary loop (Figure 2-2) also has the possibility of valve control in the liquid line. This enables the system to distribute the flow between both condensers. This is favourable in case of short periods of large sub cooling with respect to the present set point. By distributing more flow through the radiator with the highest effective deep space temperature a set point change to a lower set point can be avoided. The mixed point liquid flow temperature will than stay high enough to keep the required pre-heater power in an acceptable range.

2.4 Principal functionality of the components

Component	Function
Pump	Transport the fluid through the loop
Accumulator	Regulate the evaporator temperature in the tracker Account for the expansion of the working fluid
Accumulator Peltier elements	Regulate evaporation set-point in all operation modes (cooling)
Accumulator heaters	Regulate evaporation set-point in all operation modes (heating) Emergency accumulator heat-up in case liquid line temperature approaches saturation temperature (to avoid cavitation in pump)
Valves (liquid line)	Ability to recover from a (unrealistic) vapour block in one of the condenser sections by blocking the other branch (under discussion)
Heat Exchanger	Exchange heat between hot evaporator outlet and cold evaporator inlet. Reduction of pre-heater power
Evaporator	Collect heat at the tracker electronics. The evaporation process provides the temperature stability required.
Condensers	Remove the heat from the working fluid to the radiators. The condensing process makes the heat transfer effective.
Absolute Pressure Sensors	Monitor the absolute pressure inside the loop
Differential Pressure Sensor	Monitor pump pressure head
LFM	Monitor mass flow
Pre-heaters	Heat evaporator liquid inlet to saturation point
Dallas Temperature Sensors	Monitor temperatures TTCS temperatures
Pt1000 Temperature Sensors	Control pre-heater power Control accumulator temperature Control liquid line valves (under discussion)

Table 2-1: Functional design of the loop

3 General Accumulator

3.1 Accumulator Functions

Component	Function
Accumulator	Regulate the evaporator temperature in the tracker Account for the expansion of the working fluid Account for the liquid front changes in the condenser during operation (incl. quality changes in condenser lines)
Accumulator Peltier elements	Regulate evaporation set-point in all operation modes (cooling)
Accumulator heaters	Regulate evaporation set-point in all operation modes (heating) Emergency accumulator heat-up in case liquid line temperature approaches saturation temperature (to avoid cavitation in pump)

3.1.1 Evaporation temperature set-point control

The objective of the accumulator is to control the evaporator temperature set-point and therefore the “coldplate” temperature of the Tracker electronics. The principle is based on the property that a pressurised (closed) system with liquid and vapour has the same saturation temperature and pressure everywhere in the loop (neglecting flow pressure drop differences). In the TTCS accumulator vapour and liquid are present and is the main two-phase part in the loop. By changing the accumulator saturation temperature it is possible to change and set the evaporation temperature in the evaporator.

The actual set-point temperature control is performed by heating or cooling of the accumulator. The heating is done by minco-foil heaters also attached to the accumulator wall.

3.1.2 Account for volume changes due to temperature changes

Apart from the set-point control the accumulator also accounts for the volume changes (thermal expansion) of the working fluid (CO₂) average temperature. The CO₂ liquid density-changes from the lowest average (non-operating) temperature to the highest average (non-operating) temperature have to be taken care-off by the accumulator. At the lowest temperature the accumulator should still have liquid CO₂ in the accumulator and at the highest temperature the accumulator should be able to cope with the extra liquid volume CO₂.

3.1.3 Account for volume changes during operation

An accumulator in a two-phase system differs fundamentally from an accumulator in a single-phase system. A single-phase loop accumulator has to account only for the thermal expansion. In a two-phase other phenomena are present and have influence on the accumulator operation. Most important phenomenon is the change in vapour volumes present in the condenser. As the condenser temperature change during orbit the so-called condenser front (i.e. the front were all fluid in the condensers is pure liquid) changes also. The changes in the condenser front immediately have effect on the accumulator level.

Increasing radiator temperatures/larger vapour volumes in condenser

In case of an increasing temperature in the condensers the amount of vapour in the condenser increases. As vapour density is much smaller than liquid density the same mass in the loop takes more volume, resulting in a liquid flow from the loop to the accumulator. The accumulator should be able to account for this volume.

Decreasing radiator temperatures/smaller vapour volumes in condenser

In case of a decreasing temperature in the condensers the amount of vapour in the condenser decreases. This results in a liquid flow from the accumulator to the loop. The accumulator should be able to account for this volume.

Also the decreasing and increasing volumes in the accumulator cause fluid in the accumulator to condense and evaporate. The accumulator temperature control should be able to account for this changes.

3.2 Accumulator design challenges

Although some Russian two-phase systems have flown little experience is available with two-phase accumulators in space. The main design challenges of the required CO₂-two-phase system in space are:

- Keep liquid at the entrance of the accumulator
- Keep liquid attached to the wall where controllers heat the accumulator (avoid dry-out of wick material)
- Pressure resistant upto the pressures present in the CO₂-systems

Liquid at the entrance of the accumulator

As the accumulator has to operate in space, one of the main challenges is to keep the liquid present at the connection with the liquid line. It has to be avoided that vapour CO₂ enters the loop as it will damage the pump. To keep the liquid “attached” to the entrance of the

accumulator a wick structure is used transporting the liquid to the entrance more liquid is transported to the loop.

Liquid attached to the accumulator wall

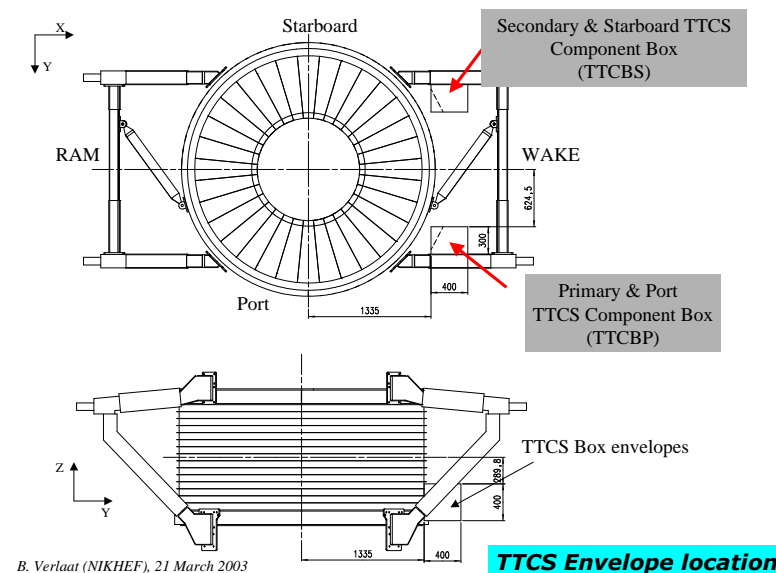
To be able to control the set-point in the accumulator, heat must be exchanged with the liquid in the accumulator. It is therefore of vital importance that the liquid is attached to the wall in μ -g conditions. This is done by wick structure (a porous structure).

High design pressures

A special CO_2 -related design challenge is the relative high design pressure of CO_2 . The accumulator structure has to deal with these pressures without losing the connection between the wick structure and the accumulator wall.

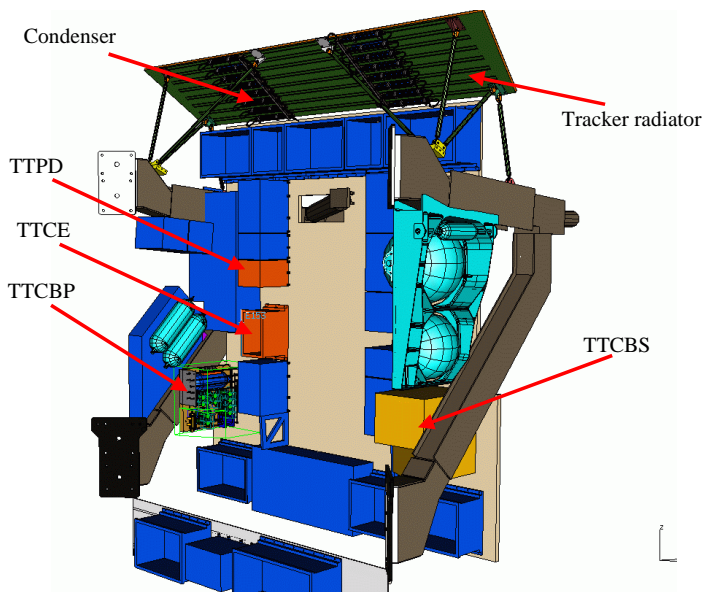
3.3 Location TTCS Component Boxes

Figure 3-1 shows the locations of the secondary (starboard) box and the primary (port) box.



B. Verlaet (NIKHEF), 21 March 2003

(Top view)



(Port side detail)

TTCS main hardware location

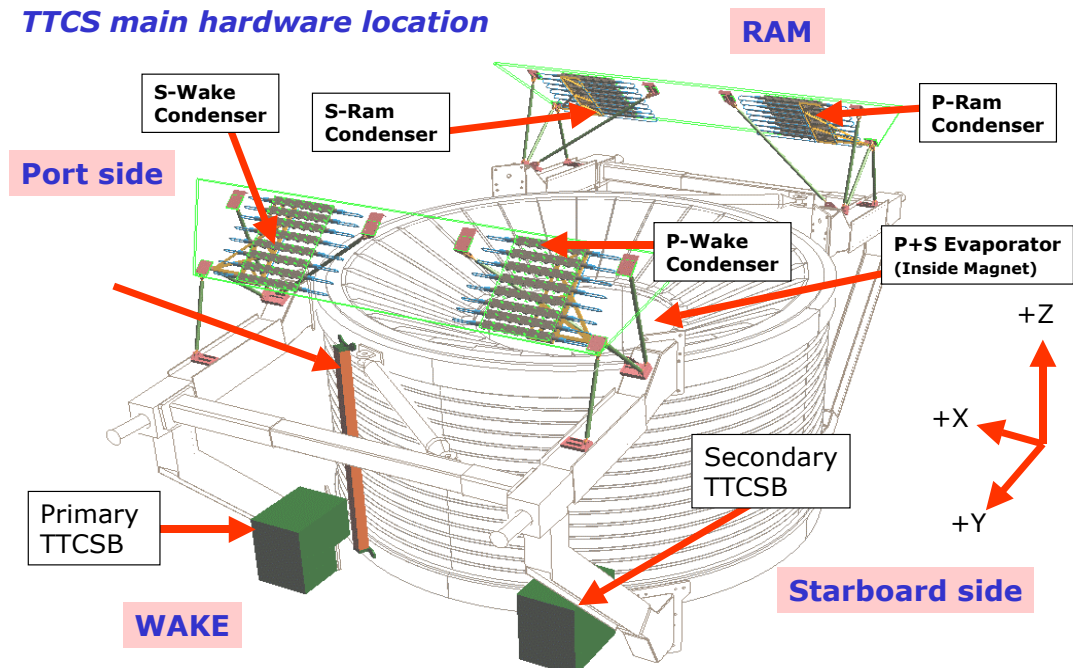
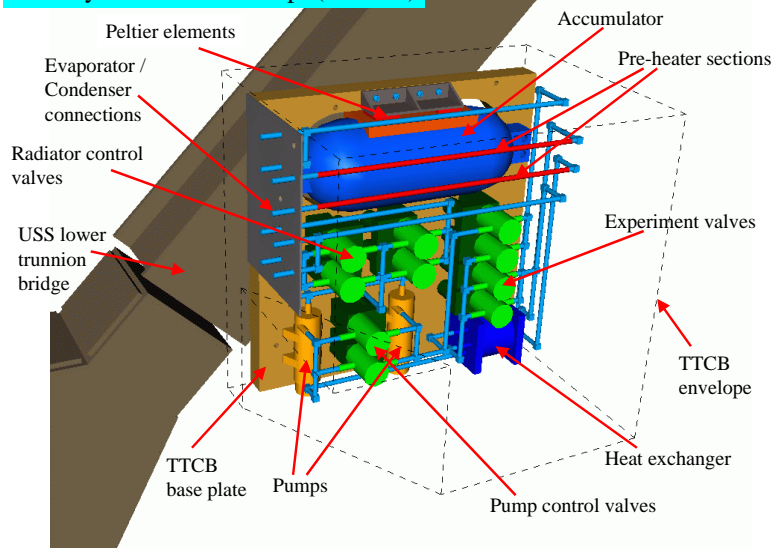


Figure 3-1: Overview and location of the TTCS hardware

The layout of the internals of the boxes is shown in Figure 3-2. *Note that the experiment valves are not part of the current design.*

Primary TTCS box concept (TTCBP)



Primary TTCS box concept (TTCBP)

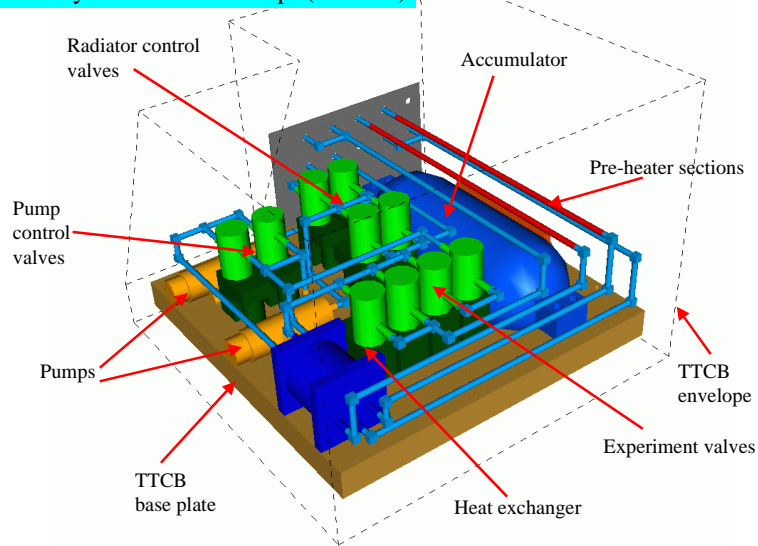


Figure 3-2: Primary TTCS concept on port side of AMS

4 Product specific Statement of Work

4.1 Tasks

This section defines the specific tasks of the accumulator contractor. The customer is Sun Yat-Sen University.

4.2 TTCS Model Philosophy

For the development of a fully compliant TTCS with the system requirements, the following Model Philosophy is proposed (see Figure 4-1). For cost reduction the Breadboard Models (BBM) and Engineering Models (EM) have been combined into one model and the Qualification Models (QM) and Flight Spares (FS) have been combined into one model.

- ❑ Breadboard Model (BBM) / Engineering Model (EM)
- ❑ Qualification Model (QM)/Flight Spare (FS)
- ❑ Flight Model (FM)

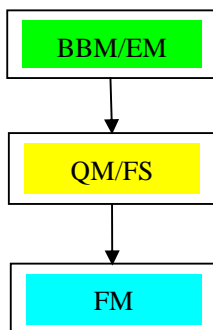


Figure 4-1: AMS TTCS Model Philosophy

When the performance tests on one of the EM (sub)systems are completed the manufacturing of the Qualification Model (QM/FS) will start. The QM/FS is fully similar to the Flight Model (FM) and will be subjected to a qualification programme (EMC, Vibration & Shock, Thermal Vacuum). The QM/FS subsystems will be stored as Flight Spare. After successful qualification of the QM/FS the Flight Model manufacturing will be started. The FM (sub)systems are subjected to a functional check prior to integration in the AMS overall system.

4.2.1 Accumulator design philosophy

Engineering Model (EM)

To test the loop performance one (1) Engineering Model accumulator is required. The Engineering Model is already mechanically exactly similar to the final Flight Model. However, it is allowed to use industrial electronic components and the requirements on the welding and integration procedures is less severe than for the Qualification Model and the Flight Models.

Qualification Model (QM)

In order to test the accumulator with respect to the vibration, EMC/EMI and Thermal Vacuum cycle requirements, a Qualification Model is build. The procedures for manufacturing (e.g. welding, integration, documentation materials) for this QM are exactly the same as for the Flight Models. Also the electronics parts of the accumulator shall be flight (and therefore space qualified) parts.

After a successful test campaign the Qualification Model will be used as Flight Spare Accumulator.

Flight Model (FM)

The TTCS system exists of two complete loops. Therefore finally two Flight Model accumulators are required.

Component		EM	QM	FS	FM	Responsible
Accumulator		1	1	1	2	Accumulator contractor

Table 4-1: Required Accumulator Models

The accumulator will go through the TTCS-box qualification programme.

However the accumulator is considered to be a critical component in the TTCS development. Therefore the accumulator should go through it's own qualification trajectory to verify the requirements listed in section 5 before integration in the QM TTCS-box, to avoid design changes late in the project.

4.2.2 Deliverable hardware

Component	Quantity Model	Need date	Requirements
Accumulator	1 EM	01-02-2007	See section 5
Accumulator	1 QM	December 2007	See section 5
Accumulator	2 FM	December 2007	See section 5

4.2.3 Deliverable documentation

Title	Responsible	Delivery (date, day-month-year)
Engineering documentation		
TN Safety Aspects Accumulator design	Contractor	31-03-2005
TN TTCS Accumulator Design EM Including: Performance analysis Interface control drawings Electrical drawings Matrix of compliance with specification Component list Mechanical parts list Material list As built configuration data	Contractor	01-07-2006
Design drawing Accumulator EM	Contractor	01-07-2006
TTCS Accumulator Verification Plan	Contractor	01-07-2006
TTCS Accumulator Test procedures	Contractor	01-07-2006
TN TTCS Accumulator Test EM Test Report	Contractor	01-07-2006
TN TTCS Accumulator Design QM (Including see EM list)	Contractor	21-11-2006
Design Drawings Accumulator QM	Contractor	21-11-2006
TN TTCS Accumulator Test QM Test Report	Contractor	21-11-2006
TN TTCS Accumulator Design FM	Contractor	21-11-2006
Design Drawings Accumulator FM	Contractor	21-11-2006
TN TTCS Accumulator Test FM Test Report	Contractor	21-11-2006
Management Documentation		
Progress reports	Contractor	Inputs on request
Schedule reporting	Contractor	Inputs on request

Level of documentation for the Test Procedures:

Procedures shall contain:

- Test objective
- A reference to the requirement in this document (section 5)
- A description of the proposed test-up
- A description of the test procedure
 - Including:
 - Accuracy of the measured values
 - Listing of (calibrated) equipment
- A clear translation from the test results to the requirement of the accumulator (section 5)

Test Reporting shall contain:

- Test objective
- A reference to the requirement in this document (section 5)
- A description of the used test-up
- A description of the final test procedure



- Anamolie Reporting (discrepancies with original test procedure)
- Test result reporting
 - Anamolie Reporting (discrepancies with expected test results)
 - Repeatability of test (if necessary)
 - Test result evaluation

5 Technical requirements

5.1 Physical requirements

5.1.1 Mass (Req. id. ACC01-01)

The accumulator should be as lightweight possible with a maximum of 2.6 kg excluding Peltier saddles, TS saddles and wire heaters (excluding liquid). The target value for the complete accumulator including Peltier saddles, TS saddles and wire heaters (excluding liquid) is 2.9 kg.

5.1.2 Volume (Req. id. ACC02-01)

The net accumulator volume should be 0.970 litres

5.1.3 Envelop (Req. id. ACC03-01)

The envelope should fit in the TTCB-P and TTCB-S boxes. The volume of these boxes is shown in Figure 5-1. The accumulator is one of the most volume consuming items. However it should fit in the overall dimensions given below and leave room for integration equipment.

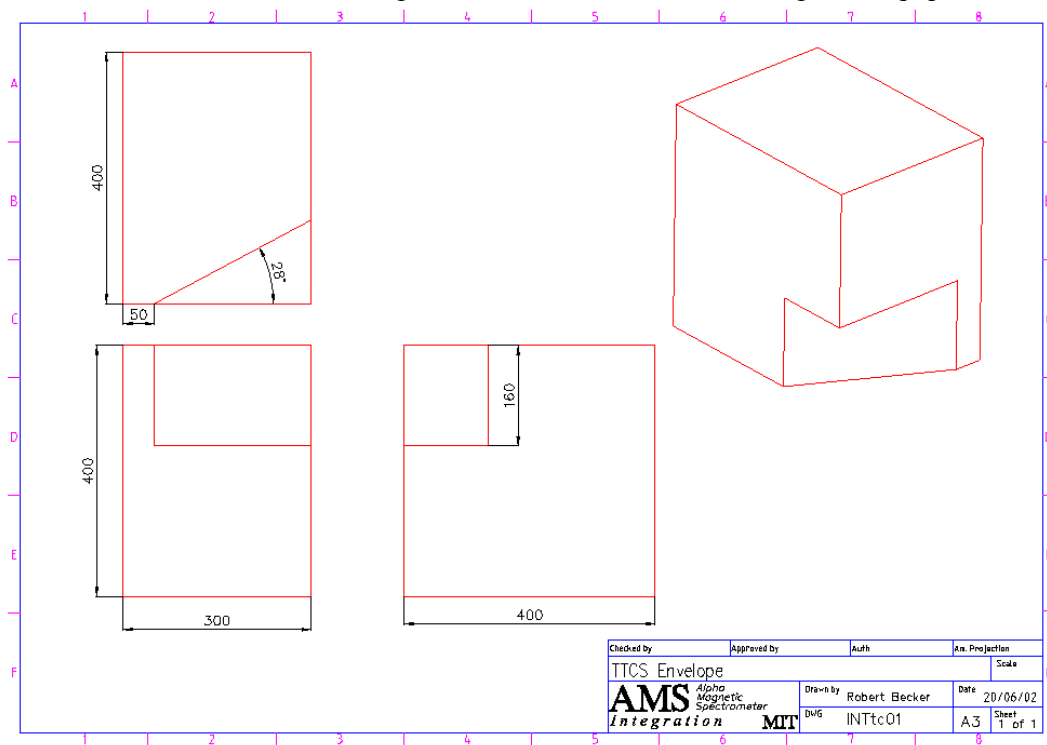


Figure 5-1: TTCS-box envelope

5.2 Mechanical Interfaces

5.2.1 Mounting interfaces (Req. id. ACC04-01)

Mounting to the TTCS box structure shall be defined in close co-operation with SYSU and INFN (Corrado Gargiulo).

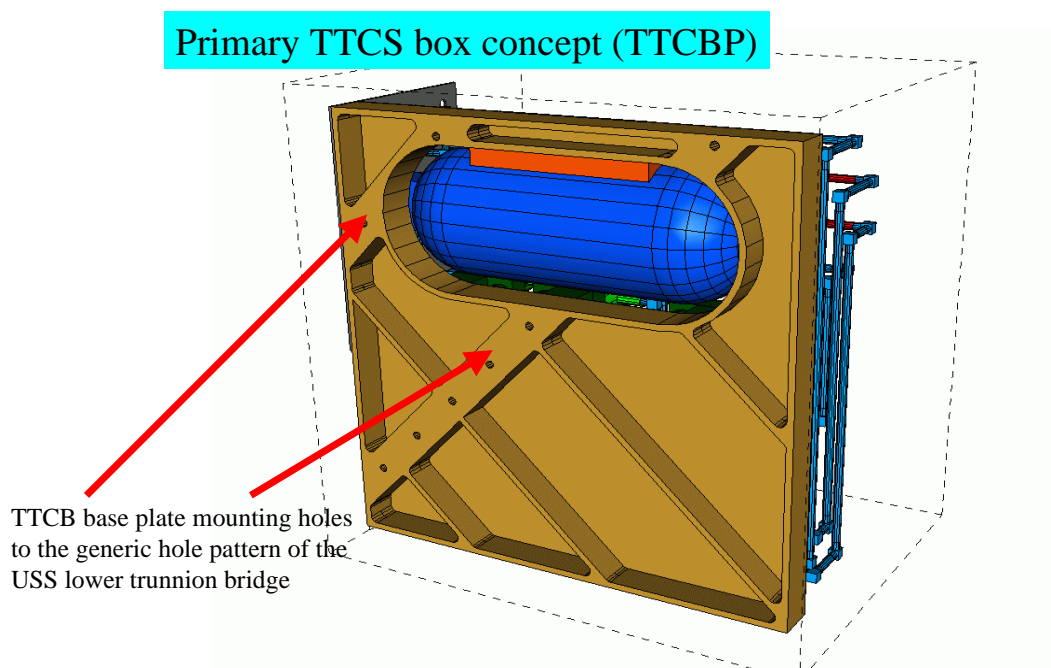


Figure 5-2: Interface concept of the TTCS-boxes with the Unique Support Structure (to be updated)

A preliminary sketch of the construction is shown in Figure 5-2.

5.2.2 Electrical interfaces (Req. id. ACC05-01)

The Accumulator will be equipped with Peltier Elements and heaters to control the temperature. The electrical/mechanical interfaces shall be such that no unwanted grounding loops occur (TBC and to be detailed).

5.2.3 Fluidic interface with the loop (Req. id. ACC06-01)

The accumulator shall provide a connection with the interface to the loop tubing. The dimensions of the connection tubing is stainless steel $D_i=6$ mm $D_o=10$ mm. Material should be 316L CRES for orbital welding to the rest of the TTCS tubes. Enough space should be left open to account for the welding procedure defined in RD-2., i.e. the accumulator connection tubes shall protrude at least 150 mm. The orientation of the tube(s) with respect to the accumulator envelope and mounting interface is TBD.

5.3 Design pressures and loads requirements

The TTCS and hence the accumulators are pressurised during STS launch. All flight hardware pressurized components shall be designed according to Military Standard document MIL-STD-1522A (Standard General Requirements For Safe Design And Operation Of Pressurized Missile And Space Systems)

In addition, the structural design of the accumulators shall be according to NASA- document JSC-2045RevA (Simplified Design Options for STS-Payloads), taking into account that the accumulators are pressurised vessels.

A summary of the pressure and structural related design rules and verification requirements is given in Appendix I.

5.3.1 Maximum Design pressure (Req. id. ACC07-01)

The Maximum Design Pressure (MDP) shall be 160 bar at temperature of 65 °C.

5.3.2 Proof pressure (Req. id. ACC08-01)

The proof system pressure at which the accumulator is to be tested shall be 1.5 times the maximum design pressure (MDP).

5.3.3 Burst pressure (Req. id. ACC09-01)

The burst system pressure shall be at least 2.5 times maximum design pressure (MDP).

5.3.3.1 Design loads and safety factors.(Req. ACC09-02)

A design load (e.g. for the accumulator mounting flanges/interfaces) according to Appendix I, Table 2, is to be taken into account. A load ultimate factor of safety FSu > 2.0 shall be applied, such that no load testing needs to be done.

5.4 Accumulator leak tightness (Req. id. ACC10-01)

The accumulator leak tightness will be lower than $1 \cdot 10^{-9}$ mbar·l/s He with the He vacuum method.

5.5 Fluid compatibility (Req. id. ACC11-01)

The accumulator materials shall be compatible with Carbon Dioxide (CO₂)

5.6 Environmental Requirements

5.6.1 Thermal Control (Req. id. ACC12-01)

The accumulator shall be designed for the operating requirements in section 5.6.2. The internal heating and/or conduction provisions for reliable operation shall be within the responsibility of the contractor.

5.6.2 Operating temperatures (Req. id. ACC13-01)

The operational temperature shall be within -40°C and $+25^{\circ}\text{C}$ (TBC)

5.6.3 Non-operating temperatures (Req. id. ACC14-01)

The storage and non-operating temperature shall be within -40°C and $+65^{\circ}\text{C}$.

5.6.4 Vacuum conditions (Req. id. ACC15-01)

The accumulator shall be able to operate in high vacuum ($1 \cdot 10^{-6}$ mbar)

5.6.5 Vibration and shock requirements (Req. id. ACC16-01)

During launch of the flight hardware, the equipment is filled with liquid and vapour. During vibration tests the accumulator is filled with Carbon Dioxide.

Mechanical structures should be designed according to NASA- document JSC-2045RevA (Simplified Design Options for STS-Payloads) to withstand launch and landing loads and frequencies. A summary of the design load factors is given in Appendix I.

The accumulator shall be subjected to a random vibration test, according to the Minimum Workmanship levels specified for AMS-02, see this specification Appendix 1, section D.

No shock verification should apply on accumulator component level.

5.6.6 Electro Magnetic Compatibility (Req. id. ACC17-01)

The accumulator shall be able to operate within a magnetic field between 140 and 1000 Gauss, depending on its final location inside the TTCS component boxes.

Remark: Note that the accumulator is located in the strong magnetic field generated by the cryogenic cooled magnet. A complete plot of the magnetic field is shown in figure 4 of appendix I. Please specify the maximum allowed magnetic field for the accumulator, and the desired orientation of the accumulator with respect to the field lines.

The functioning of the accumulator in a strong magnetic field can be tested in the AMS magnetic field test facility at MIT in Boston.

The accumulators shall also be compliant with the EMC requirements for AMS-02. The applicable AMS-02 EMC requirements are based on the ISS (external site) EMC requirements specified in SSP 30237, Rev. F. The requirements (EMC levels and tests) from SSP 30237, Rev.

F applicable for AMS-02 and hence for the accumulators, are listed in this present specification, Appendix III, Table of EMC requirements applicable to AMS-02

In this Table the applicable requirements are listed for:

- conducted and radiated emission and
- conducted and radiated susceptibility

, which are to be verified by test, according to SSP 30237, Rev. F.

As it is expected that the accumulators contain no susceptible electronics (to be confirmed by the manufacturer), the conducted and radiated susceptibility requirements may be verified by the manufacturer by design analysis.

The conducted and radiated emission requirements shall be verified by test, or, if the accumulator does not contain emitting electronics (to be confirmed by the manufacturer) by design analysis.

It is noted that later in the programme, the accumulator will be integrated in the TTCB QM box, which will be subjected to similar EMC qualification test programme.

5.6.7 Radiation levels (Req. id. ACC18-01)

The accumulator materials and electronics shall withstand a TBD radiation level.

5.7 Functional and Design Requirements

5.7.1 Accumulator Temperature control (Req. id. ACC19-01)

The accumulator shall be able to control the accumulator set-point within 1.0 °C (TBC).

It is strongly suggested to use Peltier elements for cooling action and heaters for heating.

The design of the accumulator should use a smart wick structure to avoid dry-out of parts of the wall wick material.

5.7.2 Accumulator emergency set-point change (Req. id. ACC20-01)

The accumulator shall be able to raise the evaporation set-point of the loop with 1°C /min. This should be demonstrated by test.

5.7.3 Cleanliness requirements (Req. id. ACC21-01)

The accumulator shall not contaminate the system working fluid

Metallic particles are not allowed.

The maximum number of non-metallic particles in a 100 ml sample shall be as follows and is equivalent to MIL-STD-1246 C class 100:

- > 100µm none
- 100 µm 5 max
- 50 µm 50 max
- 25 µm 200 max
- 10 µm 1200 max
- 5 µm no limit

5.7.4 Lifetime (Req. id. ACC22-01)

The accumulator shall meet the following lifetime requirements after equipment acceptance testing.

- 1 year storage on ground
- 3 months operation on ground (AMS Tracker test)
- 3 years of operation in orbit

5.7.5 Maintenance (Req. id. ACC23-01)

The accumulator should not require any maintenance.

5.7.6 Sealing (Req. id. ACC24-01)

The Qualification and Flight Models shall be welded designs. For the Engineering Model two tank parts may be connected by a bolted design with O-ring sealing (in case more convenient).

5.7.7 Orientation (Req. id. ACC25-01)

The accumulator shall be able to provide full operational performance during ground testing.

The accumulator shall therefore preferably operate in all orientations in ground test conditions

If this is not possible, the accumulator designer shall show the orientation limits of their design.

5.7.8 Operation in μ -g environment (Req. id. ACC26-01)

The contractor should verify the operation of the accumulator in μ -g environment by similarity and/or test. The design should show the capture of liquid to the accumulator wall and the continuous presence of liquid CO₂ during operation conditions.

5.7.9 Rupture criteria (Req. id. ACC27-01)

The accumulator shall be designed to leak before burst.

5.8 Compatibility with TTCS (Electronics) design

The control of the Peltier elements and accumulator heaters is performed in the TTCS electronics designed by a joined team of Sun Yat Sen University and NLR. The accumulator design should be compatible with the performance of the electronics hardware.

A powerful heater is required to provide emergency accumulator heat-up in case liquid line temperature approaches saturation temperature (to avoid cavitation in pump).

Heater element specification

- Minco Foil (To Be Determined)
- Required heater power : to be determined by the contractor. Power shall be such that a rate of change of the loop evaporation setpoint of 1 °C/min can be achieved. Current estimate by NLR is 50 Watt.
- Power supply: 28 V DC.
- Space qualified.
- Operational temperature: -40°C and 25°C.
- Non-operating temperature: -40°C and 65°C
- Set-point change rate: 1 °C/min (additional).

Peltier element specification:

- Melcor CP 1.0-127-05 L 2 inseries
- Power supply: 0-15 V DC.
- Space qualified.
- Operational temperature: -40°C and 25°C .
- Non-operating temperature: -40°C and 65°C
- Capacity to be determined by the contractor, such that a rate of change of the loop evaporation setpoint of $1^{\circ}\text{C}/\text{min}$ can be achieved. (to be discussed).

Mechanical details are shown in Figure 5-3:

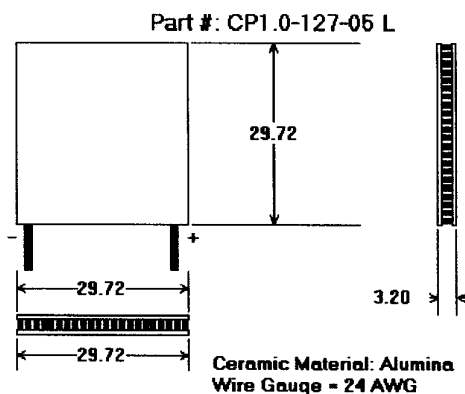


Figure 5-3: Peltier lay-out of one Melcor CP 1.0-127-05 L

5.8.1 Mechanical Interface with Peltier elements

The mechanical interface of the accumulator to the Peltier elements should be compatible with the Peltier elements selected.

5.8.2 Mechanical Interface with heater elements

The mechanical interface of the accumulator to the heater elements should be compatible with the heaters selected.

5.8.3 Thermal Interface with Peltier elements

The thermal connection between the Peltier elements and the liquid inside the accumulator should be sufficient to control the temperature of the accumulator, such that the required rate of change of $1^{\circ}\text{C}/\text{min}$ of the evaporation setpoint can be achieved.

5.8.4 Thermal Interface with heater elements

The thermal connection between the accumulator heater and the liquid inside the accumulator should be sufficient to control the temperature of the accumulator, such that the required rate of change of 1 °C/min of the evaporation can be achieved. (to be discusses with supplier).

5.9 General requirements

5.9.1 Space shuttle launch (Req. id. ACC28-01)

The accumulator shall be compliant with requirements for Space Shuttle launch.

5.9.2 ISS (external site) (Req. id. ACC29-01)

The accumulator shall be compliant with requirements for ISS (external site).

5.9.3 Prohibited materials (Req. id. ACC30-01)

The usage of the following materials on the controller and the pump, including its connectors, is prohibited: Beryllium, beryllium alloys and oxides, cadmium and zinc. Chlorinated cleaning agents shall not be used during manufacturing, testing, storage or other handling; Polyvinyl chloride products shall not be used.

5.9.4 Serial numbers (Req. id. ACC31-01)

The accumulators shall each have a unique serial number specified by the manufacturer. The serial number shall be visible at the outside surface of the accumulator.

5.9.5 Non conformance reporting (Req. id. ACC32-01)

All non-conformances related to the deliverable accumulators should be reported to the customer.

5.9.6 Quality (Req. id. ACC33-01)

The customer and/or another TTCS team member is entitled to perform an audit at the manufacturer's premises. If such need is identified.

5.9.7 Material traceability

Full material and parts traceability shall be provided from the incoming inspection at the contractor until the delivery to the customer. It is preferred to use materials and parts from a single batch.



5.9.8 Acceptance

The deliverables listed in Table 4-1 will be accepted by the customer when the accumulator is according to this specification, the incoming inspection at the contractor is successful and a traceability of the requirements in a verification matrix is delivered with the accumulator.

Appendix I: TTCS Structural Verification Requirements Summary

A. Structural verification for flight components:

Ultimate load = Ultimate factor of safety \times Limit load

Yield load = Yield factor of safety \times Limit load

A1: The “Ultimate load” is the maximum load, which the structure must withstand without rupture.

A2: The “Yield load” is the load, which the structure must withstand without permanent deformation.

A3: The “Ultimate factor of safety” (FSu) and the “Yield factor of safety” (FSy) are the safety factors needed to calculate the “Ultimate loads” and “Yield loads.” These factors are:

Table 1:

No static testing required:

FSu = 2.0

FSy = 1.25

If the structure is static tested factors of safety can be reduced to:

FSu = 1.40

FSy = 1.10

A4: The “Limit load” is the maximum load expected on the structure during its design service life. A simple way of defining the limit load is according the method from document: JSC 20545, Rev. A.

Limit load = Load factor \times Weight

The load factor is according to table 2.

Table 2

Component weight (lbs.)	Load factor (g)
<20	40
20-50	31
50-100	22
100-200	17
200-500	13

These load factors should be applied in any axis with a load factor equal to 25% applied to the 2 orthogonal axes simultaneously.

A5: All the hardware needs to have a first resonance frequency higher than 50 Hz, than no dynamic tests are required. If the resonance frequency is lower than 50 Hz but higher than 35 Hz, a sine sweep, smart hammer or modal testing is required.

B: Structural verification for pressurised systems:

Ultimate pressure = Ultimate pressure factor x MDP

B1: Where “MDP” stands for “Maximum Design Pressure”. MDP for a pressurised system shall be the highest pressure defined by the maximum relief pressure, maximum regulator pressure or maximum temperature.

B2: The “Ultimate pressure factor” is a multiplying factor applied to the MDP to obtain ultimate pressure. Pressurised components are to be designed to the following factors of safety.

Table3:

Lines and fittings:	Burst	Proof
<i>Diameter <1.5”</i>	<i>4.0</i>	<i>1.5</i>
<i>Diameter =>1.5”</i>	<i>2.5</i>	<i>1.5</i>
<i>Other components</i>	<i>2.5</i>	<i>1.5</i>

B3: In case of a pressurised system, the loads caused by the ultimate pressure needs to be added to the ultimate load caused by vehicle acceleration.

B4: To test the system for evidence of satisfactory workmanship, a proof pressure needs to be applied.

$$\text{Proof pressure} = \text{Proof factor} \times \text{MDP}$$

The proof factor is determined in table 3.

Pressurised components shall sustain the proof pressure without detrimental deformation.

C: Fracture analysis:

C1: Pressurised components or sealed containers that have a non hazardous Leak-Before- Burst (LBB) mode of failure may be classified as low risk fracture parts.

C2: To classify mechanical fasteners as fail-safe it must be shown by analysis or test that the remaining structure after a single failure of the highest loaded fastener can withstand the loads with a factor of safety of 1.0

C3: Components in a sealed box do not need structural verification when it can be proved that the released parts are completely contained and will not cause a catastrophic hazard.

C4: All fasteners larger than M3 (US #8 and above) are subject to NASA structural testing. It is recommended to use NASA provided MS- or NASA- fasteners.

D: Random vibration requirements: Minimum Workmanship Vibration Test Levels

axis	frequency	level
all axes Test duration 60 seconds per axis	< 20 Hz	0
	20 Hz	0.01 g ² /Hz
	20-80 Hz	increasing 3 dB/Octave
	80-500 Hz	0.04 g ² /Hz
	500-2000 Hz	decreasing 3 dB/Octave
	2000 Hz	0.01 g ² /Hz
	> 2000 Hz	0

Table 5-1 Table of Minimum Workmanship random vibration test levels

The vibration test consists of at least:

1. Sine sweep (before vibration testing)
2. Vibration testing as defined in table Table 5-1.
3. Sine sweep (after vibration testing)

The pass/fail criteria for vibration testing are:

- Pass: <5% shift in lowest resonance frequency between the sine sweep before and after the vibration test
- Contact NLR for consultation: 5%<Q<8% shift in lowest resonance frequency between the sine sweep before and after the vibration test
- Fail: >8% shift in lowest resonance frequency between the sine sweep before and after the vibration test

Appendix II: Example Compliance Matrix

Table.23 Matrix of compliance

Req. id.	Item	Requirement	Design or test result	Meet or not	Verification method	Remark
ACC01-01	Mass	<2.4kg(total) Excluding Peltier saddles, TS saddles and wire heaters			A + T	
ACC02-01	Net Volume	0.970 liter			A+T	
ACC03-01	Envelop	(see drawing req. doc)			M	
ACC06-01	Fluidic Interface with the loop	316 CRES. The tube shall protrude at least 150mm. working fluid :CO ₂ . D _{outer} = 10 mm D _{inner} = 6 mm			A	
ACC07-01	Maximum Design Pressure (MDP)	160 Bar			NTBT	



ACC08-01	Proof Pressure	1.5 times MDP			A + T	
ACC09-01	Burst Pressure	2.5 times MDP.			A + T	Test on sample with liquid entrance pipe and HP containers
ACC10-01	Leak tightness	Lower than 1×10^{-9} mbar*l/s He with vacuum method			T & A	
ACC11-01	Fluid compatibility	Materials, cleaning fluids, end caps shall be compatible with CO ₂ .			A	
ACC13-01	Operating temperature	-40 C~25 C			NTBT	Will be performed at box level
ACC14-01	Non-operating temperature	-40C to 65C			NTBT	Will be performed at box level
ACC15-01	Vacuum conditions	The accumulator shall be able to operate in high vacuum(1×10^{-6}			A	Show vacuum compatible materials are used Test will be performed



		mbar).				at box level
ACC16-01	Vibration and shock	table 5-1 accumulator specification			T	Perform sine sweep before and after vibration test
ACC17-01	Electro Magnetic Compatibility	as stated in specification			NTBT	Will be performed at box level
ACC18-01	Cleanliness	as stated in specification			T	
ACC22-01	Lifetime	as stated in specification			S	Show similarity with flying HP design

A = Analysis

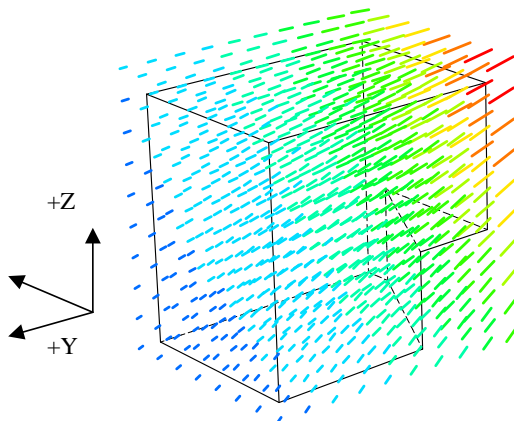
T = Test

NTBT = Not To Be Tracked

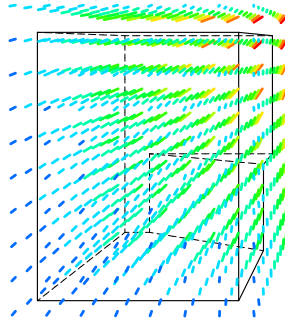
S = Similarity

M = Measurement

Appendix III: TTCS Box magnetic Field Map

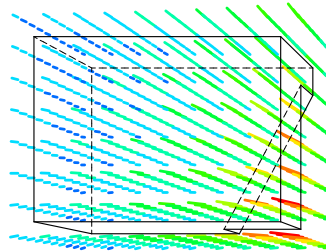


Back View (-Y)

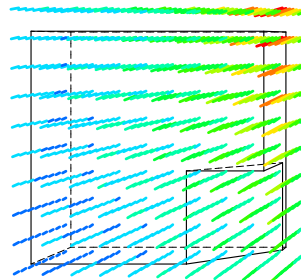


TTCS Box magnetic field map

Top View (-Z)



Side View (+X)



Magnetic
Field
(Gauss)

Magnetic field facts:

- Min: 141 Gauss
- Max: 998 Gauss
- Average: 371 Gauss
- Average X: 100 Gauss
- Average Y: 308 Gauss
- Average Z: -150 Gauss

Figure 4: TTCS magnetic field map

Appendix IV: EMC requirements applicable to AMS-02

EMC Requirements Applicable to
AMS-02

Type of Test/Requirement	Name of Test	Coverage	Applicability to AMS-
Conducted Emissions	SSP 30237, Rev F CE01	DC power, lo freq, 30 Hz to 15 kHz.	Required
Conducted Emissions	SSP 30237, Rev F CE03	DC power, 15 kHz to 50 MHz.	Required
Conducted Emissions	SSP 30237, Rev F CE07	DC power leads, spikes, time domain.	Required
Conducted Susceptibility	SSP 30237, Rev F SSP 30237 SSCN 3282 D.2 CS01	DC power leads, 30 Hz to 50 kHz.	Required
Conducted Susceptibility	SSP 30237, Rev F SSP 30237 SSCN 3282 D.2 CS02	DC power leads, 50 kHz to 50 MHz.	Required
Conducted Susceptibility	SSP 30237, Rev F SSP 30237 SSCN 3282 D.2 CS06	Spikes, power leads.	Required
Radiated Emissions	SSP 30237, Rev F RE02	Electric field, 14 kHz to 10 GHz (narrowband), 13.5 -15.5 GHz.	Required
Radiated Susceptibility	SSP 30237, Rev F RS02	Magnetic induction field	Desired by EP4/JSC
Radiated Susceptibility	SSP 30237 SSCN 3282 PIRN 57003-NA-0023 RS03PL	Electric field, 14 kHz to 20 GHz.	Desired by EP4/JSC

Table 5-2 Table of EMC requirements applicable to AMS-02

An excerpt from the applicable SSP 30237 SSCN 3282 PIRN 57003-NA-0023 RS03PL mentioned in the above table for radiated susceptibility, is given on the next page(s).



ISS PAYLOAD OFFICE IRN/PIRN/EXCEPTION

Doc. No., **SSP 57003, Initial Release**

Rev. & Title: **Attached Payload Interface Requirements Document**

PIRN NO: **57003-NA-0023**

(P)IRN TITLE: **Relaxation of EMI RS03 Requirement Per SSCN 3282**

SSCN/CR SSCN 3282

Agency Tracking No.: 57003-0026

SYSTEM/ELEMENT AFFECTED & STAGE EFFECTIVITY: **EME**

REASON FOR CHANGE: (INCLUDE APPLICABLE ICAP NUMBER):

Relaxation of RS03 requirements in accordance with SSCN 3282 .

PARAGRAPHS, FIGURES, TABLES AFFECTED (For PIRN use only)

Page **3-27**

Paragraph(s) **3.2.2.4.4**

From:

3.2.2.4.4 ELECTROMAGNETIC INTERFERENCE

Payload EPCE shall meet all Electromagnetic Interference (EMI) requirements of SSP 30237.

To:

3.2.2.4.4 ELECTROMAGNETIC INTERFERENCE

Attached Payloads shall meet all Electromagnetic Interference (EMI) requirements of SSP 30237.

Alternately, Attached Payloads may choose to accept a minimal increase of EMI risk with a somewhat less stringent Electric Field Radiated Susceptibility (RS03) requirement on equipment considered to be non-safety critical to the vehicle and crew. The tailored RS03 requirement, shown below, will hereafter be denoted RS03PL.

FREQUENCY	RS03PL LIMIT (V/m)
14 kHz - 400 MHz	5
400 MHz - 450 MHz	30
450 MHz - 1 GHz	5
1 GHz - 5 GHz	25
5 GHz - 6 GHz	60
6 GHz - 10 GHz	20
13.7 GHz - 15.2 GHz	25



UNIVERSITÉ DE GENÈVE